CATCHING PHOTONS FROM EXTRA DIMENSIONS*

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In extra-dimensional brane-world models with low tension, brane excitations provide a natural WIMP candidate for dark matter. Taking into account the various constraints coming from colliders, precision observables and direct search, we explore the possibilities for indirect search of the galactic halo branons through their photon producing annihilations in experiments such as EGRET, HESS or AMS2.

Keywords: Brane-worlds; branons; dark matter.

1. Low-tension braneworld phenomenology

According to recent suggestions our universe could be a 3-dimensional brane, where the SM fields live, embedded in a D-dimensional space-time[1] (D = 4 + N). The most important parameters of this setup being the fundamental scale of gravity in D dimensions M_D (which is no longer the Planck scale M_P) and the brane tension $\tau = f^4$. Besides the SM fields, other new excitations appear on the brane: Kaluza-Klein gravitons[2] and brane fluctuations $\pi^\alpha, \alpha = 1, 2, ...N$, where N is smaller or equal than the number of extra dimensions.[3] These branons are the Goldstone Bosons associated to the spontaneous breaking of the translational invariance in the extra dimensions induced by the presence of the brane. However, in the general case, translational invariance is not an exact symmetry of the bulk space, i.e: branons acquire a mass M. For $f \ll M_D$ (low tension), KK gravitons decouple from the SM particles. Consequently, at low energies the only relevant degrees of freedom are the SM particles and the branons whose interactions can be described by the effective

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Lagrangian:

$$\mathcal{L}_{Br} = \frac{1}{2}g^{\mu\nu}\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha - \frac{1}{2}M^2\pi^\alpha\pi^\alpha + \frac{1}{8f^4}(4\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha - M^2_{\alpha\beta}\pi^\alpha\pi^\beta g_{\mu\nu})T^{\mu\nu}_{SM} \tag{1}$$

in which, one can see that branons interact by pairs with the SM and with a coupling controlled by the brane tension scale f. For simplicity, we assume that all branons have the same mass, $M_{\alpha\beta} \equiv M\delta_{\alpha\beta}$. Therefore branons are a kind of new scalar fields, whose properties (stability, weak couplings and masses) coincide with those expected for a WIMP (Weakly Interacting Massive Particle).[4]

From the above effective Lagrangian it is possible to obtain the branon production cross sections for different colliders,[5] the typical signature being missing energy and missing P_T, and thus to find bounds on the f and M parameters for different values of N. Other constraints can also be obtained by computing the effect of virtual branons on various precision observables[6] including the muon $g-2$ measurements. Taking all this into account, one can calculate the rate for direct detection of branons in the current and future experiments designed for WIMP detection. Remarkably these particles can be well accommodated within all these bounds and still they offer definite predictions for future direct search experiments.[4] In addition WIMPs are expected to annihilate in the galactic halo producing photons in different ways. Such photons could be caught by detectors on Earth or in space, thus providing a new indirect way to detect their presence which could nicely complement the above mentioned more direct searches. In the following we analyze the potential detection of these photons coming from the galactic halo branons.

2. Gamma rays from branon annihilation

The photon flux in the direction of the galactic center coming from dark matter annihilations can be written as:[7,8]

$$\frac{d\,\Phi^{DM}_\gamma}{d\,\Omega\,d\,E_\gamma} = \frac{J_0}{NM^2}\sum_i\langle\sigma_i v\rangle\frac{d\,N^i_\gamma}{d\,E_\gamma} \tag{2}$$

where J_0 is the integral of the dark matter mass density profile, $\rho(r)$, along the path between the galactic center and the gamma ray detector:

$$J_0 = \frac{1}{4\pi}\int_{path}\rho^2\,d\,l, \tag{3}$$

N is the number of dark matter species with mass M and $\langle\sigma_i v\rangle$ is the thermal average of the annihilation cross section of two dark matter particles into another two particles. On the other hand, the continuum photon spectrum from the subsequent decay of particles species i presents a simple description in terms of the photon energy normalized to the dark matter mass, $x = E_\gamma/M$. Thus, for each channel i, we have:

$$\frac{d\,N^i_\gamma}{d\,x} = M\frac{d\,N^i_\gamma}{d\,E_\gamma} = \frac{a^i}{x^{3/2}}e^{-b^i x}. \tag{4}$$

where a_i and b_i are constants. In the case of heavy branons, if we neglect three body decays and direct production of two photons, the main contribution to the photon flux comes from branon annihilation into ZZ and W^+W^-. The contribution from heavy fermions, i.e. annihilation in top-antitop can be shown to be subdominant. The concrete values for the above constants in those channels are: $a^{ZZ} = a^{W^\pm W^\mp} = 0.73$ and $b^{ZZ} = b^{W^\pm W^\mp} = 7.8$.[7,8]

On the other hand, the thermal averaged cross-section $\langle \sigma_{Z,W} v \rangle$ which enters in eq. (2) has been calculated in[4] and in the non-relativistic limit is given by:

$$\langle \sigma_{Z,W} v \rangle = \frac{M^2 \sqrt{1 - \frac{m_{Z,W}^2}{M^2}} (4M^4 - 4M^2 m_{Z,W}^2 + 3m_{Z,W}^4)}{64 f^8 \pi^2} \tag{5}$$

The produced high-energy gamma photons could be in the range (30 GeV-10 TeV), detectable by Atmospheric Cerenkov Telescopes (ACTs) such as HESS, VERITAS or MAGIC. On the contrary, if $M < m_{Z,W}$, the annihilation into W or Z bosons is kinematically forbidden and it is necessary to take into account the rest of channels, mainly annihilation into the heaviest possible quarks.[9] In this case, the photon fluxes would be in the range detectable by space-based gamma ray observatories[10] such as EGRET, GLAST or AMS, with better sensitivities around 30 MeV-300 GeV.

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